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Stormwater Simulation Based on The Concept of Sustainable Development of Sponge City Construction

Stormwater Simulation Based on The Concept of Sustainable Development of Sponge City Construction

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Abstract. In recent years, urban flood disaster has intensified due to the frequent urban stormwaters in China. It has seriously restricted the healthy sustainable development of cities. Therefore, it is very important to simulate the urban Stormwater waterlogging process by using a mathematical model, and to assess the risk of waterlogging and drainage capacity for urban flood prevention and mitigation. The stormwater of the Xiaoyi City in China is simulated by using MIKE 21 and MIKE URBAN models. The main conclusions include: (1)The Stormwater flooded area and depth has simulated in the urban stormwater, and the Stormwater on "2016.7.19" was used to verify the models. The results show that the model has good applicability. (2)Under the different rainfall intensities of 1a, 3a and 5a, the Stormwater flooded area, which water depth ≥27 cm and duration ≥30 min, is increased from 1.46 km^2 to 3.21 km^2 and 4.49 km^2, respectively, accounting for the total waterlogging area about 42.3%, 44.3%, and 48.0%. (3)The lack of drainage capacity is the main reason for the floods in the study area. Under the current conditions, with a drainage capacity of less than 3 years, the total length of the pipe network is about 18.77 km and accounting for 86.57% of the total length of the pipe network. These results can provide technical support for the urban flood control in the study area.

1. Introduction

In recent years, with the intensification of global climate change, the frequency of meteorological events has increased significantly in China's extreme disasters. The sudden urban heavy floods caused by stormwater has become increasingly prominent due to the rapid development of the urban. This has aggravated the task of urban flood control and drainage. The healthy development of the urban was also seriously restricted[1-3]. According to the relevant investigation, 62% of the urban an urban waterlogging occurs in the three years between 2008-2010, more than three times the number of 137[3-6]. For example, the "7·18" Stormwater in Jinan in 2007, the "July 21"Stormwater in Beijing in 2012 and the "July 23"Stormwater in Wuhan in 2015 all caused huge ecological damage, economic losses and social harm[6-9]. Therefore, carrying out a numerical simulation of urban waterlogging has important practical significance for studying urban stormwater problems.

Based on MIKE FLOOD model[9-11], this paper takes the old urban area of Xiaoyi city in Shanxi Province, as the research object. One-dimensional(MIKE 11) urban pipe network model and a two-dimensional(MIKE 21) FLOOD model was building, which based on the data of Xiaoyi City's natural geography, hydrology and meteorology, urban construction and planning and urban drainage facilities. The current disaster risk of heavy rain is assessed in the old urban area of Xiaoyi City. The results will be provided technical support for optimizing the urban flood control and establishing a perfect drainage system in the healthy sustainable development of Xiaoyi City.

2. The study area

Xiaoyi City is located in the central part of Shanxi Province in North China and belongs to Luliang District. The terrain is high in the west and low in the east. The altitude of Xiaoyi City ranges from 730m to 760m from east to west. The annual average precipitation is 428.8 mm which is mostly dominated by light rain. The moderate rainfall mainly comes in the summer (May to September). Heavy rains occur relatively few times, usually comes from June to August. The research area locates in the southeast of the downtown area of Xiaoyi Urban. It is the old area of Xiaoyi Urban and the area of study about 3.1 square kilometers. The main river system in the study area is a moat surrounding the ancient urban wall. The study area as the position of the Figure1.

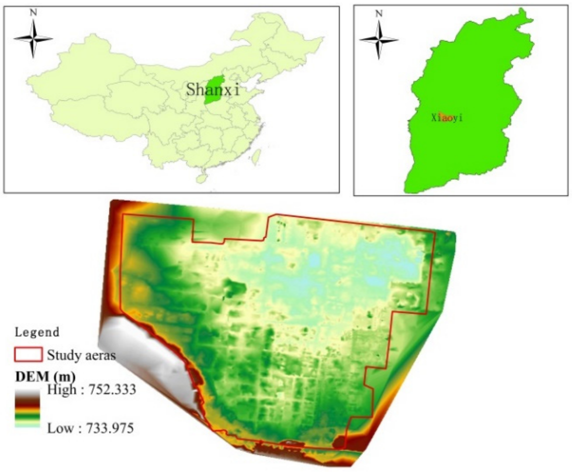

Figure 1. Study area location

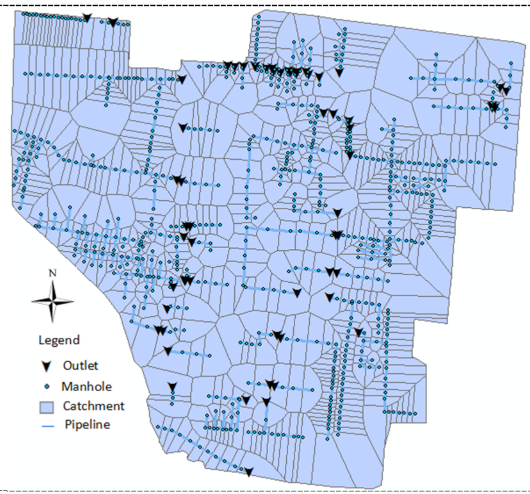

Figure 2. Pipe network generalization and watershed division

3. Model and Methods

In this paper, the MIKE FLOOD coupling model is used to link the one-dimensional river network model (MIKE 11), the one-dimensional urban pipe network model (MIKE URBAN) and the two-dimensional surface runoff module (MIKE 21) [11-12]. Based on the following three assumptions: ① under the same rainfall intensity in the study area; ②Select rainwater wells on all trunk and main pipes as nodes; ③When the water collection area is divided, it is divided according to the location of the node according to the principle of proximity. MIKE URBAN and MIKE 21 were used to construct the model in the study area through the MIKE FLOOD coupling model.

4. Data and model verification

4.1Rainfall data

Combined with the existing research results, this paper determines the calculation of the short-duration design Stormwater pattern using the Chicago model rain pattern[14]. The determined rain peak coefficient is 0.35 and combined with the storm intensity formula, the design rainfall distribution process in the study area is calculated.

4.2Pipe network and parameter setting

The urban pipe network model is generalized according to the current data of the pipe network. The model includes 658 collection wells, 60 discharge ports, and the number of pipe sections is 684, with a total length of 21.68 km. The MIKE URBAN automatically divides the catchment function and divides the study area based on the position of the catchment well, using the principle of proximity. The constructed pipe network generalization and watershed division results show in Figure 2.

The MIKE URBAN model is used to calculate the hydraulic pipe network. The main parameters involved are average slope flow rate, simulation time step, pipeline Manning number and local head loss of inspection well[15]. Actual parameter settings are shown in Table 1.

Table1. The hydrodynamic parameter of the pipe network model

name	parameter	Remarks
Simulation time step	Step size：1s - 10s	Model calculation automatically adjusts the simulation step size from 1s to 6s depending on the stability
Average slope flow rate	0.3 m/s	The average flow rate of each catchment determines the confluence time of the section
Pipeline Mannings	85	The pipe material is reinforced the concrete pipe
well diameter	Greater than the maximum diameter of the connected pipe	Ensure the drainage capacity of the pipeline

4.3Land use type analysis

According to the existing information, in the general classification of the underlying surface, the paper is mainly divided into the following categories: water, roads, grassland, buildings and other. The runoff coefficient of different land types in the study area is determined according to China’s “GB50014-2006,2014”. The flow coefficients and areas of different land types used in this paper are shown in Table 2.

Table 2. Various types of land area and runoff coefficient

Land use classification	Area（ha）	Runoff coefficient
Water	3.32	1
Grassland	15.93	0.15
Road	35.62	0.85
Building	98.92	0.9
Other	159.28	0.6

4.4Terrain data and processing

The DEM map used in the ancient urban of Xiaoyi Urban is extracted from the GIS based on the elevation and elevation lines in the measured 1:1000 CAD data. The grid size is finally determined to be 4×4 m according to the density of the elevation points of the original terrain, and the cumulative grid number is 196,293.

4.5Model verification

In this paper, the real stormwater process of “2016.7.19” is taken as the inflow condition. The flooding of the Xiaoyi City is simulated by using“2016.7.19” stormwater to verify the model. The maximum water depth (maximum submerged range) occurs at 7:00, which is the same as the actual occurrence of the maximum accumulated water depth. In order to analyze the water accumulation in different sub-areas in the study area, four areas with large historical water depths (Table 3) are extracted for verification analysis.

.Table 3. The simulated and real submerged areas in the “2016.7.19” Stormwater

Number	Submerged area	Calculate the depth of water（cm）	Actual water depth（cm）
1	Xinhua Coal Washing Plant	28	20~30
2	Loudong Village Cross	70	60~70
3	Kuixing Building North Point	54	40~50
4	Qiaobei Middle School South	61	55~65

The calculation value of the maximum accumulated water depth in the four submerged areas of the Xiaoyi City is consistent with the actual situation. The analysis and judgment are according to the calculated data of water depth by investigation of the witnesses, public social media (news media pictures), the inundation depth estimation of the features. This is indicated that the model is constructed reasonably, the basic data and parameters are reliable, and the constructed model can good reflect the real situation of the study area.

5. Status assessment analysis

5.1Evaluation of drainage capacity of the urban pipe network

The overflow of the pipeline (whether the pipe headline exceeds the ground line) is used as an evaluation index to evaluate the drainage capacity of the pipe network. The equal formula is:

$$\delta = H - W \qquad (1)$$

Where: H indicates the head of the pipe network node(m), W indicates ground elevation(m);When $\delta \leq 0$, it means that the pipeline drainage capacity meets the corresponding design return period requirements; When $\delta > 0$, it means that the drainage capacity of the pipeline does not meet the requirements of the corresponding design return period[16]. On this basis, the design Stormwater of 1 year, 3 years and 5 years are used as the model boundary condition to evaluate the drainage capacity of the pipe network, and the evaluation results of the pipe network capacity and the distribution of the non-standard pipeline are obtained. Results are shown in Figure 3, The statistical result data is shown in Table 4.

Table 4. The result of pipe network drainage capacity assessment under current conditions

Pipe network drainage capacity	<1a	1a~3a	3a~5a	>5a	Total
Length（km）	17.28	1.49	0.26	1.75	21.68
Ratio	79.70%	6.88%	1.2%	8.05%	100%

The results of Table 4 show that the total length of the pipe network with a drainage capacity of less than 3 years under the current conditions of the study area is about 18.77 km. It is mainly distributed in the central area of the study area, accounting for 86.57% of the total length of the calculation pipe network, which is far lower than the current urban pipe network drainage system of Xiaoyi Urban meeting the requirements of 3a planning and design. Among them, under the current conditions, the total length of the pipe network with a drainage capacity less than 1a is about 17.28 km. It accounts for 92.06% of the total length of the pipe network with a drainage capacity of less than 3a; and accounts for 79.70% of the total length of the pipe network in the study area. It indicates that the drainage capacity of the pipe network system in the study area is seriously insufficient.

5.2Flooded area and time-space distribution

The waterlogging disaster standard adopted in this study is: ①the accumulated water time exceeds 30 minutes, and the accumulated water depth exceeds 0.15 m; ②In the concave bridge area, the accumulated water time exceeds 30 minutes, and the accumulated water depth exceeds 0.27 m. When the two conditions are satisfied simultaneously, it can be considered waterlogging disaster. Otherwise, it can be considered acceptable stagnant water and does not constitute a disaster[17,18]. Figure 4 to Figure 6 show the maximum submerged water depth distribution of hydropower in one-year, three-year and five-year design stormwater.

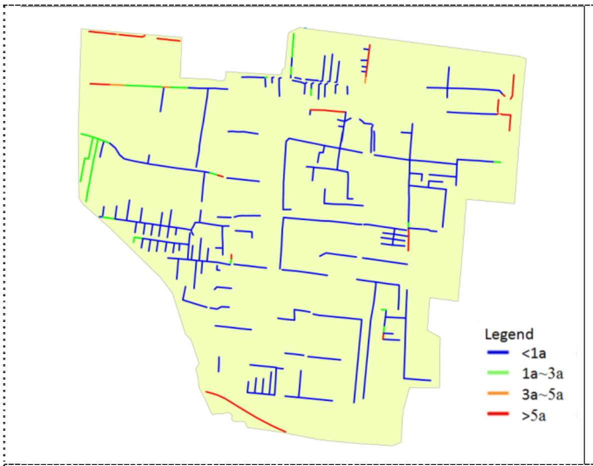

Figure 3. Pipe network drainage capacity assessment chart under current conditions

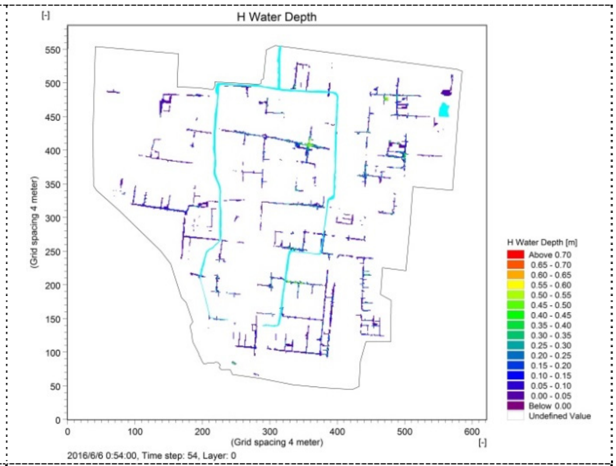

Figure 4. Depth distribution map of torrential rain in 1a design under current conditions

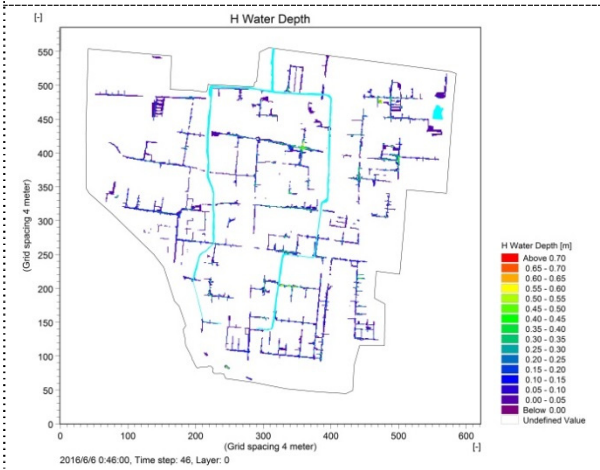

Figure 5. Depth distribution map of torrential rain in 3a design under current conditions

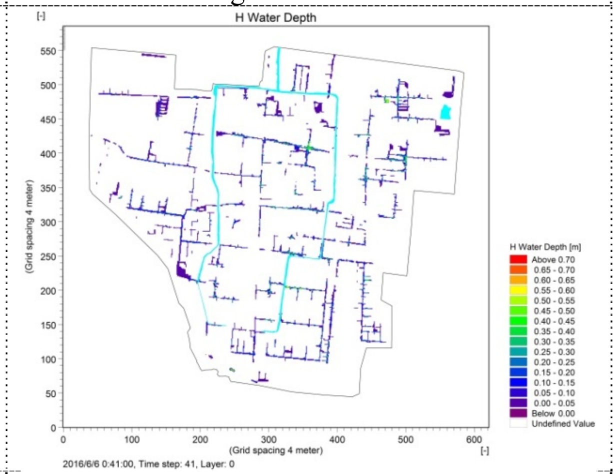

Figure 6. Depth distribution map of torrential rain in 5a design under current conditions

As the rainfall intensity in the study area increases, the waterlogging point does not change substantially, but the depth of water accumulation and the area of water accumulation increase accordingly. The main water level in the study area is located at the intersection of Loudong Village, the North Point of Kuixing Building and the road near Health Center of Dongguan village. The terrain of these blocks is lower than the surrounding area, and the bottom of the surrounding buildings is relatively high, resulting in the formation of some depressions. Through the calculation and comparison analysis of the simulation results, the statistical data of the depth of the water in the study area, the duration of the accumulated water and the area of the inundated water are obtained, which shown in Table 5.

Table 5. The maximum submerged areas in different return periods under current drainage capacity

Water depth and duration	Maximum submerged area（$\times 10^4 m^2$）		
	1a	3a	5a
15～27cm，≥30min	1.99	4.03	4.86
27～40cm，≥30min	0.84	1.76	2.43
40～50cm，≥30min	0.30	0.61	0.95
≥50cm，≥30min	0.32	0.84	1.11
Total	3.45	7.24	9.35

According to the current situation of the area of the study area, it is not difficult to see that the depth of water accumulation in the study area is mainly concentrated in 15~27 cm which accounting for 57.7%, 55.7% and 52.0% of the total submerged area. With the increase of rainfall intensity, the area of flood disasters（Water depth≥27 cm and duration≥30min）in the territory gradually increased from 1.46×104m2 to 3.21×104m2 and 4.49×104m2, the submerged area accounting for 42.3%, 44.3% and 48.0% of the total submerged area. The area of accumulated water with a depth of ≥50 cm and a duration of ≥30 min gradually increases from 0.32×104m2 to 0.84×104m2 and 1.11×104m2 which accounting for 9.3%, 11.6% and 11.9% of the total submerged area.

5.3Analysis of the causes of flood disasters

Based on the geographical location, climate and current status of the whole research area, the reasons for the torrential rain in the study area are analyzed:①The precipitation is mostly light rain, and moderate rain mainly comes in May-September. Heavy rains and heavy rains occur less frequently and are generally come in June-August. In order to maximize the benefits, the hydrological and climatic factors considered in the planning and design of the pipe network system are not as heavy as the rains and heavy rains in the southern cities. As a result, the urban pipe network system that originally met the planning and design requirements is no longer up to standard.②The the study area is originally an old urban. With the development of urbanization, the urban area has significantly increased. Under the current conditions, its drainage capacity of the pipe network has been difficult.③The old urban area module is solidified, the pipeline system is difficult to change and upgrade due to long-term disrepair, and the drainage capacity of the pipe network is declining year by year, especially in the central area of the old urban. Therefore, the serious shortage of drainage capacity of the current pipeline network system is the leading cause of frequent disasters in the Storm waters in the study area. On the basis of the difficulty in upgrading and upgrading the underground urban pipe network system in the ancient urban of Xiaoyi Urban, it is necessary to give full play to the effects of absorption, storage and slow release of rainfall by different land types such as buildings, roads, green spaces and water systems, and increase rainwater harvesting. The use of, effectively reduce the runoff coefficient, reduce the flow of production, thereby reducing the loss caused by floods in the ancient urban of Xiaoyi Urban and the frequency of disasters.

6. Conclusion

The Stormwater in the Xiaoyi City is simulated based on the models of MIKE FLOOD model, MIKE URBAN and MIKE 21 to assess the risk of waterlogging and drainage capacity. The main conclusions include:（1）Under the current conditions, the overall drainage capacity of the pipe network system in the study area is severely insufficient. Therefore, the rain cannot be discharged in time through the pipe network, which is the main reason for the frequent occurrence of waterlogging disasters in the study area.（2）In order to reduce the probability and waterlogging loss caused by urban Stormwater, it is necessary to improve the drainage capacity of pipelines, and to reduce the capacity of urban underlying surface production and remittance, give full play to the effects of different types of precipitation on absorption, storage and slow release of precipitation, staggering the blocks. The convergence of rainwater and reduce the runoff coefficient and reduce the flow.（3）Through The MIKE FLOOD platform, the simulated model of the stormwater in the ancient urban of Xiaoyi Urban has a good simulation effect, and the results are basically consistent with the actual situation, which indicates that the coupled model has high applicability and operability in urban stormwater simulation analysis. Provide technical support and theoretical basis for the urban to make more scientific urban planning and design, risk analysis and flood prevention and disaster prevention plan.

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